Modeling the economics of intermittent energy

Liv Lundberg
Kristian Lindgren
Chalmers University of Technology
Fossil Fuels Just Lost the Race Against Renewables

This is the beginning of the end.
New installed capacity each year, in GW

Global cumulative installed wind turbine capacity, in GW

Data from BP Statistical Review of World Energy, June 2014
Global cumulative installed photovoltaic (PV) power, in GW

Data from BP Statistical Review of World Energy, June 2014
Wind power as a share of total electricity production in the country

Data from BP Statistical Review of World Energy, June 2014
Solar power as a share of total electricity production in the country

Data from BP Statistical Review of World Energy, June 2014
Characteristics of Variable Renewable Electricity (VRE)

- High investment costs
- Low running cost
- Intermittent
The merit order effect

Price

$p_1$

$p_2$

Capacity
Europe's storms send power prices plummeting to negative

LONDON/FRANKFURT | BY KAROLIN SCHAPS AND VERA ECKERT

German power prices negative over weekend
13 May 2014  by Craig Morris  Comments (2)

Germany set a new record on Sunday, May 11, by getting nearly three quarters of its electricity from renewable sources during a midday peak. Nonetheless, Craig Morris says the resulting negative prices are both good news and bad news.

On May 11th, power prices were negative for several hours in Germany. (Source: EPEX)
Electricity production and spot prices in Germany, January 2015

Source: https://www.energy-charts.de/power.htm
Electricity production and spot prices in Germany, May 2015

Source: https://www.energy-charts.de/power.htm
How will this affect the electricity system in the long run?
The model

• Equilibrium model (parallel work with an agent based model).
• Maximizes consumer and produced surplus over each year
The model

Price: \( p(q) = p_0 \left( \frac{q}{q_0} \right)^{\frac{1}{\varepsilon}} \)

Electricity produced: \( q_i = q_0 \left( \frac{r_{c,i}}{p_0} \right)^\varepsilon - Q \)

Capacities of gas and coal are chosen so that consumer and producer surplus is maximized.

\[
\Pi(C) = \sum_{t=1}^{24\times6} S_{c,t}(C) + \sum_{t=1}^{24\times6} \sum_{i=1}^{N} (p_t(C) - r_{c,i})q_{i,t}(C) - I_a C
\]
The model

Demand and solar profile over 24 hours

Sustained fossil capacity

• It takes time for old power plants to shut down

• What happens when the fossil capacity is kept in the system while solar and wind power is increased drastically?
Results – sustained fossil capacity

Hourly prices over an average day, with increasing shares of solar

![Graph showing hourly prices over a day with increasing solar shares.](image)
Results – sustained fossil capacity

[Graph showing load factor for coal and gas over time]
European utilities

How to lose half a trillion euros

Europe's electricity providers face an existential threat

Oct 12th 2013 | From the print edition
Results – optimized fossil capacity

Hourly prices over an average day, with increasing shares of solar
Results-optimized fossil capacity

Electricity production over the day

- Gas
- Wind
- Coal
- Solar
Results - optimized fossil capacity

Yearly electricity production, by technology, as a function of solar electricity share
Results - optimized fossil capacity

0% electricity production from wind power

30% electricity production from wind power
Results - optimized fossil capacity

Electricity production on the six typical days

0% electricity production from wind power

30% electricity production from wind power
Results - optimized fossil capacity

Yearly electricity production, by technology, as a function of wind power electricity share
Results - comparison

Sustained fossil Capacity

Optimized fossil capacity
Results - comparison

Profit for variable renewable energy

- Optimized fossil capacity
- Sustained fossil capacity
Results - comparison

Profit for variable renewable energy

- Optimized fossil capacity
- Sustained fossil capacity
Conclusions

• Variable Renewable Energy causes electricity prices to decrease, as long as fossil capacity is sustained
• Potentially higher price peaks in the long run if fossil capacity is “optimized”
• Profitability of the VRE’s themselves decreases as their share of the system increases.